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PATENT SPECIFICATION

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(54) APPARATUS FOR PROVIDING A DISPLAY

(71) We, XEROX CORPORATION, of Rochester, New York State, United States of America, a Body Corporate organized under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to apparatus for providing a display.

Flat display panel devices continue to receive much attention because they provide distinct advantages over conventional cathode ray tubes which are now the standard display device. U.S. Patent 3,612,758, sets forth those advantages and discloses a flat display panel employing migration of color pigment particles to form an image on a matrix addressable panel. Specifically, that display panel utilizes a suspension of colored particles maintained in a thin layer of dyed dielectric liquid, enclosed between two electrodes, one of which is transparent. Upon the application of a D.C. voltage of suitable polarity between the electrodes, colored particles will move through the liquid toward the transparent electrode and deposit on it. The dielectric liquid is dyed a contrasting color to the colored particles such that only when those particles are deposited on, or are in very close proximity to, the transparent electrode will the particles be visible, otherwise the color of the display as viewed through the transparent electrode will be that of the dyed dielectric liquid.

The flat panel display of U.S. Patent 3,612,758 has several problems associated therewith which are difficult to solve. One problem relates to the usage of a dyed liquid; the dye tends to be absorbed on the colored particles and the tansparent electrode, diminishing the contrast and appearance of the display. Particle settling over a period of time (due to gravity), particle agglomeration and clamping together over a period of time, and particle adherence to the transparent electrode pose additional problems. Another problem is that particles must move substantial distances during display operation, thereby causing the display to operate with relative slowness. Also, because D.C. fields are used, it is probable that electro-chemical changes will take place in the display over extended periods of time.

Recent literature has propsed magnetic particle displays in lieu of cathode ray tube displays in order to overcome the size limitations, high voltage and high power requirements of cathode ray tube displays. The model magnetic particle display proposed uses tiny particles each of which is a plastic magnet composed of ferrite powder held together by a suitable binder. The particles are each substantially 0.8 millimeter in diameter, black in one hemisphere and silvered (or otherwise light reflective) in the other hemisphere. A magnetic field generated by four conductors nearest a desired image spot controls the orientation of the particles proximate that spot such that their orientation with respect to a viewer conveys optical images by scattering of ambient light. Because of the close proximity of the conductors to other image spots, there arises a problem of discrimination, that is, the ability to address a chosen image spot without addressing other proximate image spots. In order to prevent clustering of the magnetic particles, the particles are individually encapsulated with small amounts of clear liquid in small, thin walled transparent spherical shells. The encapsulated particles are then cemented onto a suitable substrate to form the display panel. The requirements of a magnetic field to provide particle orientation, the need for individual encapsulation of the particles and individual attachment of the particles to a suitable substrate, and discrimination problems present serious drawbacks to utilization of magnetic particulate displays of the type described. Also, magnetic particle displays of the type described have neither an effective built-in

threshold behaviour nor an effective memory capability.

According to the present invention, there is provided apparatus for providing a display, comprising a body at least substantially transparent to light, said body having at least one cavity; at least one particle in dielectric liquid in said at least one cavity, said at least one particle being optically anisotropic, and electrically anisotropic or magnetically anisotropic in that liquid; and means for respectively applying at least one electric field or at least one magnetic field to said at least one particle, so that said at least one particle will rotate in accordance with said electrical anisotropy, or so that said at least one particle will rotate in accordance with said magnetic anisotropy, and thereby provide a display in accordance with said optical anisotropy.

Especial reference should be made to the claims appended to this specification, because those claims also form part of the disclosure of the present invention. The subordinate claims included in said appended claims indicate some preferences for carrying out the present invention.

The present invention will now be described by way of example with reference to the accompanying drawings, wherein:

Figure 1 is a perspective, exploded view of one embodiment of display apparatus.

Figure 2 is a sectional view along line 2—2 of Figure 1.

Figures 3*A*, 3*B*, 3*C* relate to manufacturing the display apparatus of Figure 1.

Figures 4, 5, 6, 7 show other embodiments of display apparatus.

Referring to Figure 1, general reference 2 designates, as a whole, a display which has a display panel 4 sandwiched between substrates 6 and 8. Intermediate the display panel 4 and substrate 6 is a first grid 10 of parallel electrical conductors 10'; and a second grid 12, having parallel electrical conductors 12' oriented orthogonal to the conductors 10' of the first grid 10 is provided between the substrate 8 and the display panel 4. At least one of the substrates 6 and 8 and at least the conductors of the grid adjacent that substrate are optically transparent so that ambient light can impinge upon the display panel 4 and so that the display provided by panel 4 can be viewed, as shown in Figure 2, where substrate 6 and conductors 10' are of optically transparent materials so that the ambient light incident upon the display panel 4 will provide an image visible at I.

The display panel 4 includes minute particles 14 which are optically anisotropic. The particles 14 are surrounded by a transparent dielectric fluid which, due to the optical anisotropy of the particles 14 and the difference in Zeta potential due to coatings used to achieve that optical anisotropy, causes the particles 14 to have an electrical anisotropy. In addition to the particles 14 and the dielectric liquid which surrounds those particles, the panel 4 includes a solid, optically transparent support material 15 which permits the particles 14 to have desired rotational freedom without having substantial translational freedom.

As shown in Figure 2, the particles 14 of the panel 4 can be small spheres, typically 0.05 to 0.5 millimeters in diameter, which have hemispherical coatings of different Zeta potential. The difference in Zeta potential can be achieved by applying to one hemisphere of each of the spheres 14 a coating that exhibits optical absorption characteristics, as illustrated by their dark shading, and applying to the other hemisphere of each of the spheres 14 a coating that exhibits light reflectance characteristics, as illustrated by the absence of dark shading. The differenct between said light reflectance-light absorption characteristics of the hemispheres provides the desired optical anisotropy. The spheres 14 can comprise black polyethylene with light reflective material, for example titanium oxide, sputtered on one hemisphere to so as provide the spheres 14 with the desired light reflective hemispheres and light absorptive hemispheres. As shown in Figure 3*C*, each of the spheres can be located within a cavity 16 of a slab of transparent support material 22 (see later below). Cavities 16 have a diameter slightly larger than the diameter of spheres 14 so that spheres 14 have desired rotational freedom without having substantial translational freedom. Filling the voids between spheres 14 and cavities 16 is an optically transparent dielectric liquid 18. Due to the differences in Zeta potential between the hemispheres and the immersion of each of the spheres 14 in the dielectric liquid 18, the spheres 14 acquire an electrical charge.

When a power source 19 is coupled across one of the electrodes 10' of the grid and one of the electrodes 12' of the grid 12, as shown in Figure 2, the positively charged hemisphere will be attracted to the more negative electrode 12', and the spheres 14 within the field develpd by the energized electrodes 10' and 12' will rotate, but without substantial translation, so that the light reflecting hemispheres are oriented toward I. Thus, a light spot on a dark brackground is provided. By reversing the polarity of source 19, a black spot on a light background can be provided. By sequentially coupling the source 19 to selected ones of the crossover points of electrodes 10' and 12', as is done in conventional matrix addressing, an image is provided viewable at I.

The display 4 can be formed by thoroughly

mixing the optically anisotropic particles 14 with an uncured (liquid), optically transparent material, for example, an uncured elastomer such as Dow Corning Sylgard 182. ("SYLGARD" is a registered trade mark). This optically transparent material is then cured, such as in the case of Sylgard 182 by rapid heating to an elevated temperature of substantially 140 degrees Centigrade and maintaining the elastomer at that temperature for substantially 10 minutes, which provides the solid slab structure shown in Figure 3*A* in which the spheres 14 are in contact with a slab 22 and thereby refrained from either rotational or translational movement. Following curing of the slab 22, the slab is placed in a dielectric liquid plasticizer 18, as shown in Figure 3*B*, for a short period of time, typically overnight, with the plasticizer at room temperature. The dielectric liquid plasticizer 18 can be silicone oil, e.g. Dow Corning 10 Centistoke 200 oil when the elastomer is Sylgard 182. Another satisfactory elasomer/plasticizer combination is Stauffer and Waker V-53 elastomer with the above silicone oil.

When the cured slab 22 is placed in the plasticizer 18, the plasticizer is believed to be absorbed by the slab material resulting in a swelling of the slab material. The spheres 14 are made of a material which does not readily absorb the plasticizer or absorbs the plasticizer at a substantially slower rate than the material of slab 22 absorbs the plasticizer, with the result that the swelling of the slab 22 creates spherical cavities 16 around the spheres 14, as shown in Figure 3*C*. The cavities 16 are filled with the plasticizer, and this structure allows easy rotation of the spheres 14 while permitting no substantial translation of spheres 14.

The slab 22 need not be an elastomer. The slab 22 can be of rigid plastics material, e.g. rigid polyethylene, rigid polystyrene or rigid plexiglas. ("PLEXIGLAS" is a registered trade mark). Encapsulation can be achieved by using encapsulant molten or dissolved in volatile solvent. An uncured material (e.g. an epoxy resin) can be used as encapsulant provided that the cured material is light transparent. It is necessary that the material of slab 22 absorb the plasticizer more readily than do the spheres 14 in order that the cavities 16 may be formed. When the material of slab 22 is elastomer, the spheres can be suitable plastics material (e.g. suitable polyethylene or polystyrene) whic do not absorb the plasticizer as readily as elastomers. When the material of slab 22 is plastics material, the spheres must be of a material (e.g. glass) which does not absorb the plasticizer, or absorbs the plasticizer substantially less than the plastics material.

The anisotropic spheres 14 can be coated with dielectric coatings. Black coatings may be obtained by the simultaneous evaporation of magnesium fluoride and aluminum in a vacuum chamber, whereas white coatings may be obtained by the slow deposition of indium.

The described encapsulating method can also be used to provide magnetic displays. In such displays, sphereical balls are magnetized and given an optical anisotropy corresponding to their North and South poles. The balls will rotate in response to a proximate magnetic stylus.

When using a matrix of X and Y electrodes for accessing a display, it is desirable that the display exhibit a sharp threshold behaviour so as to minimize the complexity of the electrical switching equipment. A threshold behaviour can be achieved with the display panels of Figures 1 and 2 by slightly deforming the spherical cavities 16 so that they take on an asymmetrical shape which slightly pinches the spheres 14. The applied electric field would have to overcome the frictional forces produced by the pinching before rotation of the spheres 14 is achieved. Thus, the display panel exhibits a threshold behavior. Deformation of the spherical cavities 16 could be achieved by a piezo-electric device provided in contact with one of the substrates 6 and 8 and pulsed slightly prior to the application of an electric field to a matrix crossover point defined by a pair of the electrodes 10^1 and 12^1 of the grids 10 and 12.

Another useful threshold behaviour configuration for use with matrix switching is shown in Figure 4 wherein parts corresponding to like parts of Figures 1 and 2 have the same reference numerals. The device of Figure 4 has additional electrodes 30 and 32 on opposite sides of the panel 4 which are electrically isolated from electrodes 10^1 and 12^1 by electrically insulating layers 34 and 36. At least one of the electrodes 30 and 32 and its adjacent electrically insulating layer are optically transparent. Electrodes 34 and 36 have a higher resistance per unit length than the resistance per unit length of electrodes 10^1 and 12^1 and are biased by source 35 to have a polarity opposite to that applied across electrodes 10^1 and 12^1 by the source 19. The electric field provided by source 35 and electrodes 30 and 32 will tend to orient spheres 14 in a common direction to start with, and will attract the spheres 14, causing the spheres 14 to press lightly up against and have frictional contact with the proximate portion of their associated cavities 16. To achieve orientation of the spheres 14 in a selected area of the display, the appropriate X and Y electrodes are activated by source 19 which, as noted, has a polarity opposite to that applied by source 35 across high resis-

tance electrodes 32 and 34. The higher resistance electrodes may be thought of an electrically semi-transparent, because they are unable to convey enough charge to the vicinity of the X and Y matrix intersection to nullify the field created by electrodes 10' and 12' for times long compared to the rotation time of the spheres 14. Hence, as the desired X and Y matrix intersection is activated or accessed, the field across the spheres 14 proximate that intersection quickly decreases in magnitude. When the X—Y field produced by source 19 reaches the value of the field created by the high resistance electrodes and source 35 (the threshold field), the total electric field across the sphere encapsulation is now zero and the spheres are freed from their frictional contact with the cavity walls and are free to rotate. With further increases in the X, Y field provided by source 19, the spheres move towards the opposite cavity walls while rotating to a new orientation. When the spheres have rotated sufficiently, the X, Y matrix produced by source 19 is removed, allowing the field of the high resistance electrodes to drive the spheres back against the cavity walls with the spheres retaining their new orientation. Thus, the display of Figure 4 has both threshold and memory capabilities.

The threshold and memory capabilities associated with the disclosed displays depend in some way upon utilization of frictional forces between the spheres 14 and their encapsulating cavities 16. The frictional forces can be controlled still more by using spheres having a non-smooth or roughened surface texture.

Threshold and memory capabilities are also provided by the display of Figure 5 wherein the spheres 14' are of a ferromagnetic material and a sheet of ferromagnetic material 40 is provided between the substrate 8 and the electrodes 12'. Either the spheres 14' or the sheet 40 is permanently magnetized. In this structure, the spheres 14' are attracted magnetically to the sheet 40 and are therefore pressed against the lower surface of their encapsulating cavities 16. The combination of the friction of the spheres 14' against their encapsulating cavities 16 and the hysteresis of the induced magnetism present resistance to the rotation of the spheres 14' which must be overcome before spheres 14' will rotate under the influence of the electric field provided by electrodes 10' and 12 and source 19.

Threshold and memory capabilities can also be achieved by utilizing the frictional forces between the spheres and their encapsulating cavities. This could be achieved by using spheres having a non-uniform surface texture, that is, rough in one hemisphere and smooth in the other. Alternatively, instead of frictional forces, the spheres may be held in place against the walls of their encapsulating cavities by means of geometric constraints. For example, if slightly ellipsoidal optically anisotropic particles are used and sufficiently large cavities are generated by the swelling of the elastomer, the particles will offer greater resistance to motion when held against the cavity walls, but can rotate easily when allowed to float in their cavity.

A threshold behaviour can also be achieved by having the surface area of one Zeta potential material of the particles disproportionate with respect to the surface area of the other, different Zeta potential material of the particles. This will create, in cooperation with the dielectric fluid, a net electrostatic charge on the particles which will provide a memory affect by causing the particles to be pushed against a wall of their encapsulating cavities in the presence of an electric field.

To avoid electrolysis problems that may arise in displays using DC field, a display using an AC field is shown in Figure 6. In addition to the DC biased electrodes used to achieve orientation of the particles, AC biased electrodes are also used. Referring specifically to Figure 6, AC electric fields are applied to strip electrodes 50, 51, 52 and 53, with the fields being of opposite polarity both side to side and top to bottom, as shown. Taking advantage of the finite rotational torque of the particles 14, the electrodes 50—53 are switched in polarity at a uniform rate, causing the particles to oscillate slightly about an equilibrium position as indicated by the double-headed arrows. At the correct switching rate the particle orientation is trapped in a kind of dynamic potential well. Upon perturbing the electric field by adding the field of DC switching electrodes 10' and 12' or changing the field values of the illustrated strip electrodes, the particles will rotate 180° to their opposite orientation. Upon re-establishment of the original AC electric field condition, the particles will now be stable about this new orientation. It is clear that the change in orientation can have a threshold characteristic.

A color display is also contemplated. Because of the binary nature of the display, the particles may be coated on one hemisphere with one color material and on the other hemisphere with another color material, provided these different materials have different Zeta potentials. The display panel could be broken up into several sections or stripes so that balls having different color coatings can be separately accessed for providing rotation thereof.

Addessing of the display can be achieved by other than matrix switching. In Figure 7,

a layer of photoconductive material 60 is provided between electrode 12¹ and display panel 4. Light passing through optically transparent substrate 8 and/or electrode 12¹ to the photoconductive material 60 will change the electric field across those portions of the photoconductive material, thus change being sufficient to allow the electric field provided by source 19 to rotate the spheres 14.

The particles or spheres used in the display panel 4 can be encapsulated with freedom of rotational movement by ways other than swelling of an elastomer. For example, the optically anistotropic spheres could be mixed with glass or other optically transparent dielectric spheres of somewhat larger diameter. The larger spheres will tend to settle in close-packed array and the small anistropic spheres will tend to occupy the interstitial positions between the larger spheres. The small, optically anisotropic spheres will be free to rotate but will be allowed only limited translational movement. An additional encapsulation technique could utilize a several micron thick layer of photoresist, suitably etched and subsequently baked to hardness to provide chambers for each anisotropic particle or group of such particles in a manner analogous to the chambering of eggs in an egg carton.

WHAT WE CLAIM IS:—

1. Apparatus for providing a display, comprising a body at least substantially transparent to light, said body having at least one cavity; dielectric liquid in said at least one cavity; at least one particle in dielectric liquid in said at least one cavity, said at least one particle being optically anisotropic, and electrically anisotropic or magnetically anisotropic in that liquid; and means for respectively applying at least one electric field or at least one magnetic field to said at least one particle, so that said at least one particle will rotate in accordance with said electrical anisotropy, or so that said at least one particle will rotate in accordance with said magnetic anisotropy, and thereby provide a display in accorance with said optical anisotropy.

2. Apparatus of claim 1, wherein said body is in the form of a layer.

3. Apparatus of claim 1 or 2, wherein said body is elastomeric.

4. Apparatus of claim 3, wherein said body comprises a silicone elastomer.

5. Apparatus of claim 1 or 2, wherein said body is rigid.

6. Apparatus of claim 5, wherein said body comprises rigid plastic material.

7. Apparatus of any one of claims 1 to 6, wherein at least one said cavity will not allow substantial translation of said at least one particle therein.

8. Apparatus of any one of claims 1 to 7, wherein at least one said cavity is asymmetric or capable of being deformed to become asymmetric.

9. Apparatus of claim 8, comprising piezo-electric means for deforming at least one said cavity.

10. Apparatus of any one of claims 1 to 9, wherein said dielectric liquid is at least substantially transparent to light.

11. Apparatus of any one of claims 1 to 10, wherein said dielectric liquid comprises silicone oil.

12. Apparatus of any one of claims 1 to 11, wherein said dielectric liquid has been absorbed into said at least one cavity.

13. Apparatus of any one of claims 1 to 12, wherein said at least one particle has a width in the range 0.05 to 0.5 mm.

14. Apparatus of any one of claims 1 to 13, wherein said optical anisotropy is provided by a said particle having regions of different optical characteristics.

15. Apparatus of claim 14, wherein at least one said particle has a surface portion thereof which has a light absorbancy greater than the light absorbancy of another surface portion thereof.

16. Apparatus of claim 14 or 15, wherein at least one said particle has first and second surface portions thereof, said first surface portion being of a first color, said second surface portion being of a second color.

17. Apparatus of any one of claims 14 to 16, wherein at least one said particle has first and second surface portions thereof, said first surface portion being rough, said second surface portion being smooth.

18. Apparatus of any one of claims 1 to 17, wherein at least one said particle is spherical.

19. Apparatus of claim 18, wherein at least one said spherical particle has at least one hemispherical surface coating.

20. Apparatus of any one of claims 1 to 19, wherein at least one said particle is elliptical.

21. Apparatus of any one of calims 1 to 20, wherein said electrical anistropy is provided by a said particle having different Zeta potentials.

22. Apparatus of any one of claims 1 to 21, wherein at least one said particle comprises magnetic material.

23. Apparatus of claim 22, wherein said magnetic material is ferromagnetic material.

24. Apparatus of any one of claims 1 to 22, wherein said means for applying said at least one electric field is adapted to provide at least one AC electric field and/or at least one DC electric field.

25. Apparatus of any one of claims 1 to 24, wherein said means for applying said at least one electric field comprises first and

second electrode means with said body therebetween.

26. Apparatus of claim 25, wherein at least one of said first and second electrode means is in the form of a matrix.

27. Apparatus of claim 26, wherein said matrix has crossover points; and means are provided for accessing said crossover points.

28. Apparatus of any one of claims 1 to 27, wherein said means for applying said at least one electric field comprises photoconductive means.

29. Apparatus of claim 28, wherein said photoconductive means is in the form of a layer.

30. Apparatus of any one of claims 1 to 29, comprising means for preventing said rotation of said at least one particle until said at least one electric field exceeds a threshold value thereof.

31. Apparatus of claim 30 ,wherein said prevention means ocmprises third and fourth electrode means with said body therebetween, these electrode means being electrically isolated from said first and second electrode means when said apparatus is in accordance with any one of claims 25 to 27.

32. Apparatus of claim 31, when in accordance with any one of claims 25 to 27, wherein said third and fourth electrode means are adapted to be biased electrically opposite to electrical bias to be applied to said first and second electrode means.

33. Apparatus of claim 32, or of claim 31 when in accordance with any one of claims 25 to 27, wherein said third and fourth electrode means have higher resistances per unit length thereof than said first and second electrode means.

34. Apparatus of any one of claims 1 to 33, when having a flat configuration.

35. An apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Figs. 1 to 3C of the accompanying drawings.

36. An apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Fig. 4 of the accompanying drawings.

37. An apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Fig. 5 of the accompanying drawings.

38. An apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Fig. 5 of the accompanying drawings.

39. An apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Fig. 6 of the accompanying drawings.

40. An apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Fig. 7 of the accompanying drawings.

41. A method of providing apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Figs. 1 to 3C of the accompanying drawings.

42. A method of providing apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Fig. 4 of the accompanying drawings.

43. A method of providing apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Fig. 5 of the accompanying drawings.

44. A method of providing apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Fig. 6 of the accompanying drawings.

45. A method of providing apparatus of claim 1, substantially as hereinbefore described with reference to and as shown in Fig. 7 of the accompanying drawings.

46. A method of providing a display, comprising forming that display by means of apparatus according to any one of claims 1 to 40.

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Sheet 1

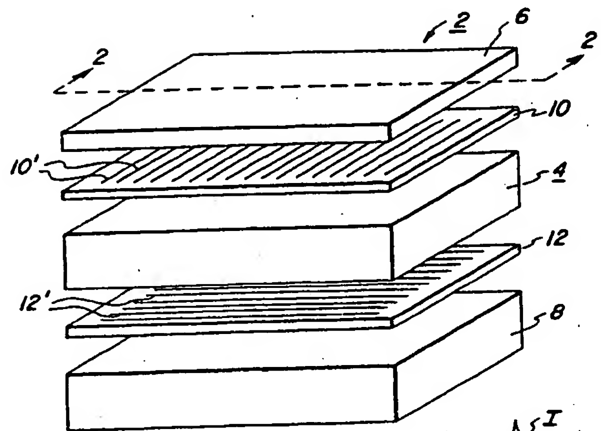

FIG. 1

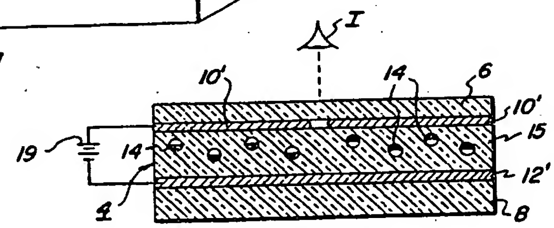

FIG. 2

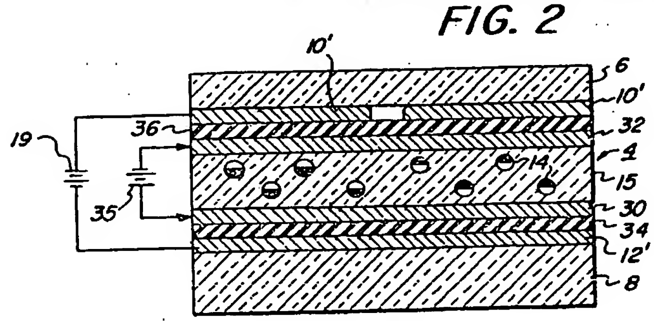

FIG. 4

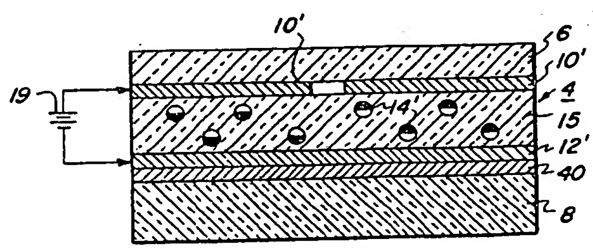

FIG. 5

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Sheet 2

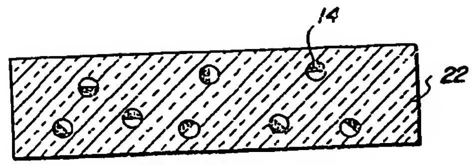

FIG. 3A

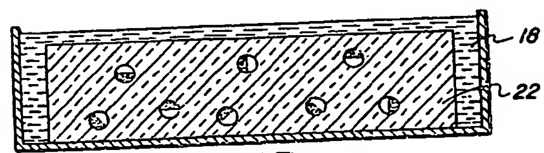

FIG. 3B

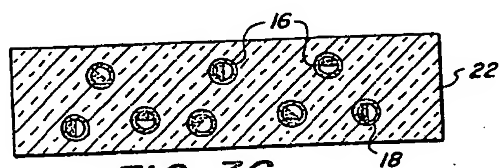

FIG. 3C

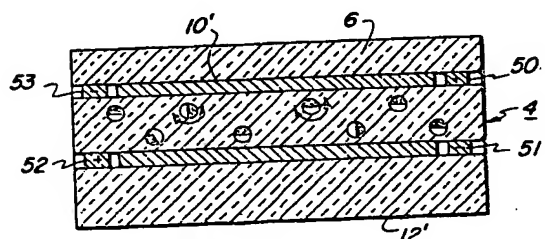

FIG. 6

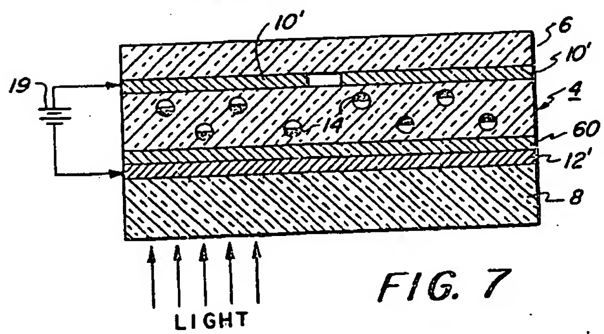

FIG. 7